GEM

GLOBAL EARTHQUAKE MODEL

working together to assess risk

The Release of the GEM Global Active Faults Database and Global Seismic Hazard Map

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CIG Webinar

2019.11.14

OPENQUAKE

Today's talk

- Intro to seismic hazard, risk, and GEM
- GEM Seismic Hazard Map and Global Active Fault Database
- Topics for hazard-related geophysics research

What is seismic hazard and risk?

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- 'Hazard' is defined as the likelihood of an event occurring
  - Usually ground motions (PGA, etc.) at/above some value in some time interval at some site
- Hazard is the combination of earthquake occurrence and ground motion predictions
- Probabilistic Seismic Hazard Analysis (PSHA) considers all ~reasonably~ possible earthquakes, with assigned probabilities, and many ground motion models (with uncertainty) to compute a probabilistic result
- 'Risk' is the product of the consequence of the event and the hazard
  - Probabilistic or deterministic (scenario events)

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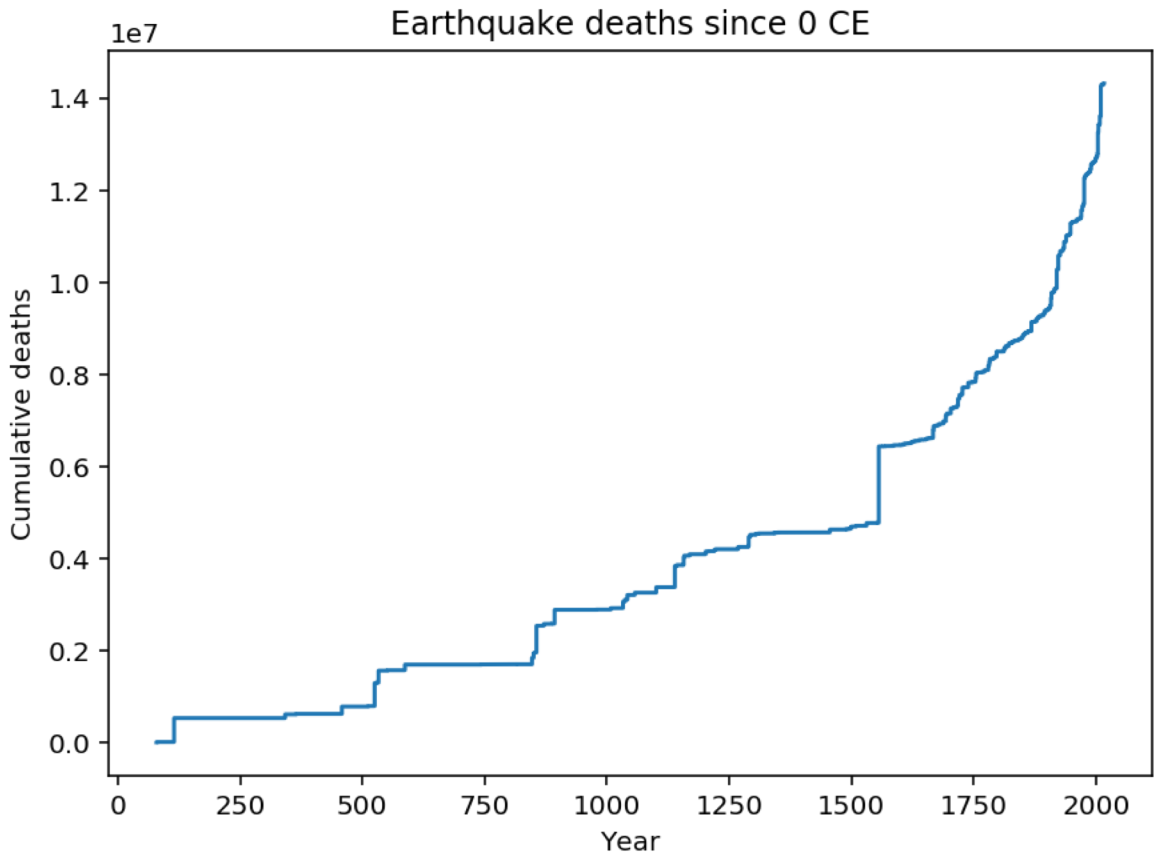
Earthquake losses

- ~1.6 million earthquake deaths since 1900 (Wikipedia)
- $ 661 Billion USD losses 1998-2017 (UNISDR)



Data from https://ourworldindata.org/natural-disasters

Who is GEM?

GEM

- Global Earthquake Model Foundation: Small non-profit based in Pavia, Italy
  - Public-private partnership
  - ~ 25 people (engineers, geoscientists, programmers, staff)
- Focused on earthquake risk reduction through better hazard and risk estimation
  - Data collection
  - Hazard and risk modeling
  - Software development
- Not a research institution
  - Research important but secondary to implementation
  - Work closely w/ govs to better prepare for earthquakes

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What does GEM produce?

GEM

- Datasets:
  - Global earth science datasets (e.g., faults, EQ catalogs)
  - Local to global human exposure data, vulnerability fns
- Hazard and risk models
  - Regional, national, subcontinental scale PSHA models
    - New models, collaborative models, reimplimentations
  - Seismic risk models of various scales
  - Data + models used in building codes, insurance rates,…
- Software
  - OpenQuake: Capable, high-performance PSHRA software written in Python (GPL)
  - github.com/gem/oq-engine

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We're hiring!

GEM

- Looking for a hazard modeler (post-doc or post-MS)
  - Strong background in scientific programming
  - Solid understanding of seismology, tectonics or PSHA

- Good work environment
  - Impactful
  - Great team
  - Fun, challenging work

- Pavia is lovely
- Email jobs_hazard@globalquakemodel.org

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GEM Global Seismic Hazard Model / Mosaic

GEM

- Global hazard compilation made from 30 constituent models

- Models implemented in, or converted to, the OpenQuake format and run on OpenQuake at GEM

- Individual models updated and re-run regularly as new info available
  - Mosaic is dynamic, always up-to-date, reproducible

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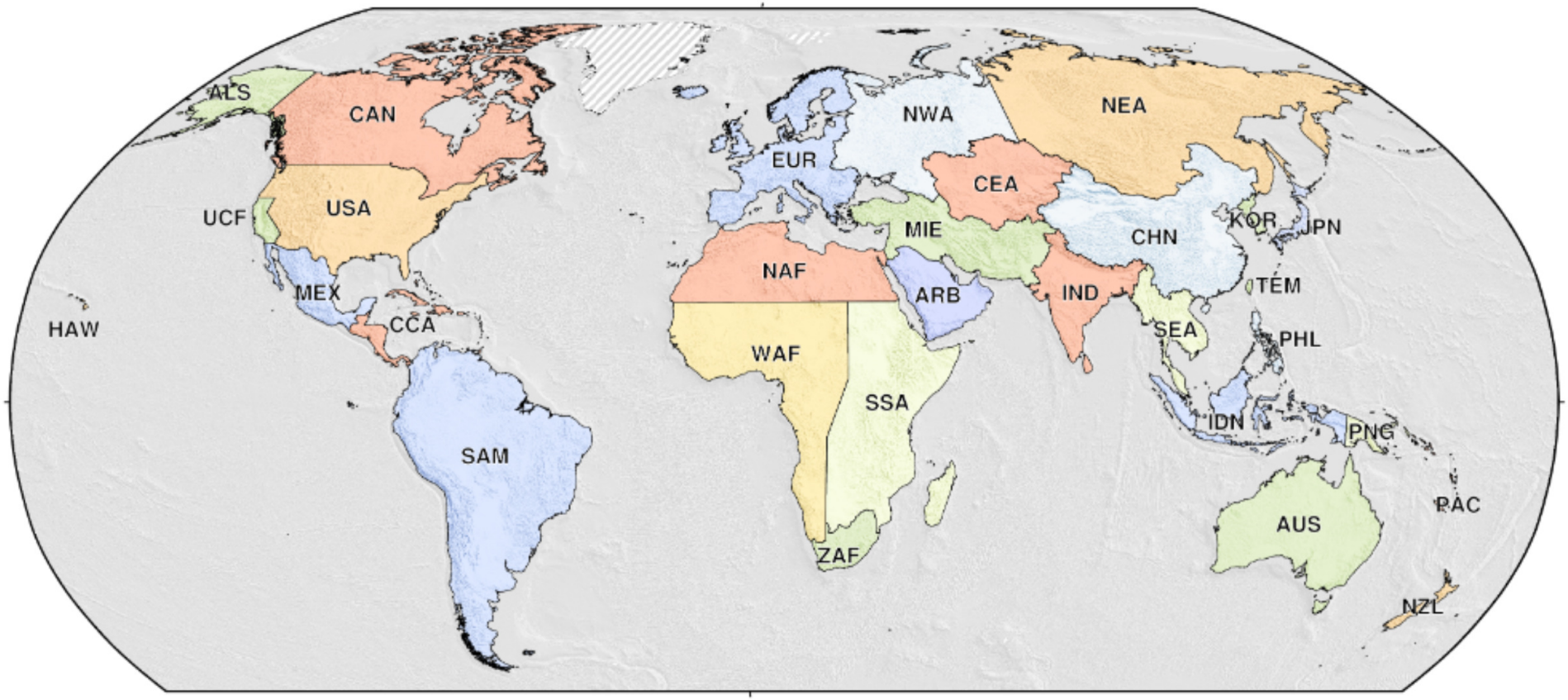
Hazard Mosaic Models



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GEM Global Seismic Hazard Map

GEM

- Hazard results computed from each model on a uniform grid
- Metric: PGA at 10% probability of exceedance in 50 years
- ~3.5 million hazard sources producing ~1.8 billion distinct ruptures, ~90 ground motion prediction equations

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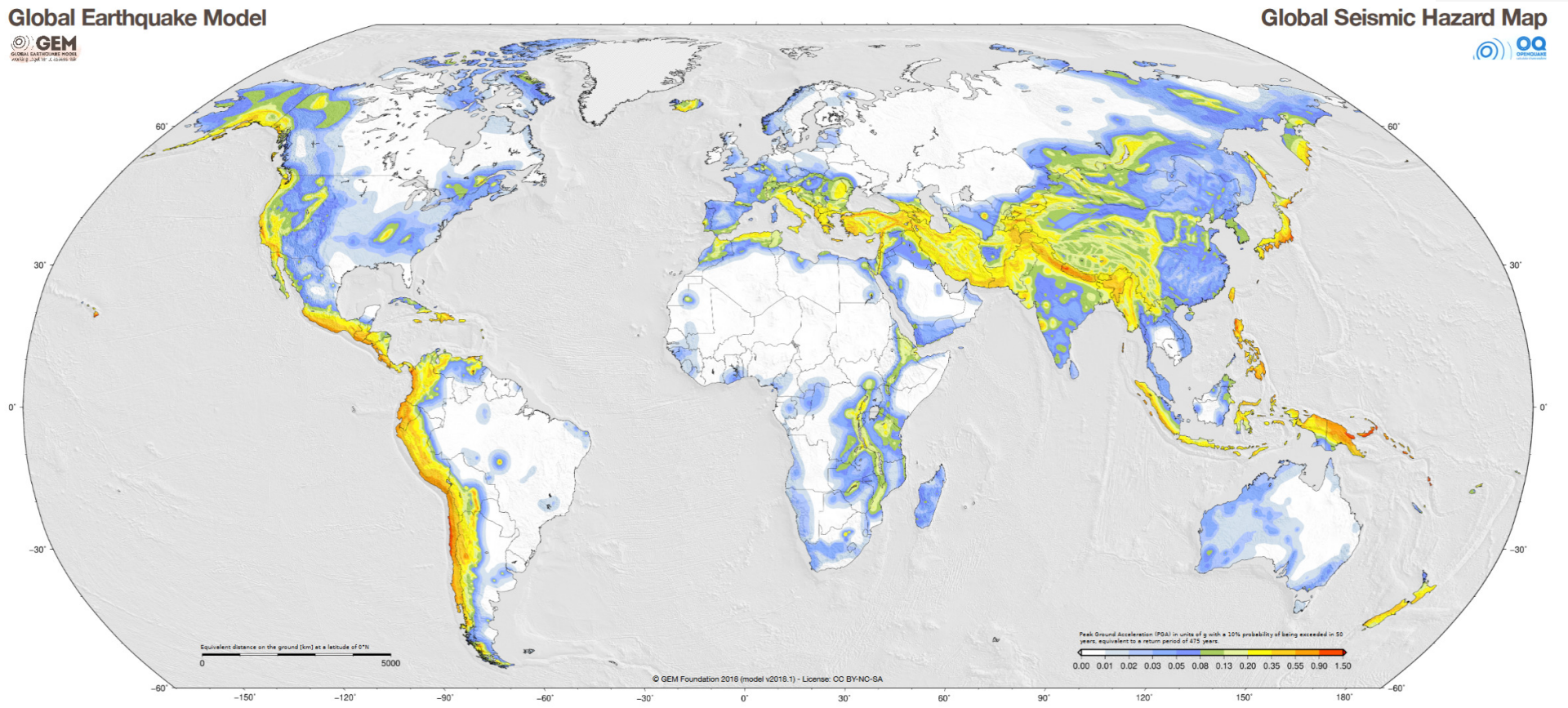
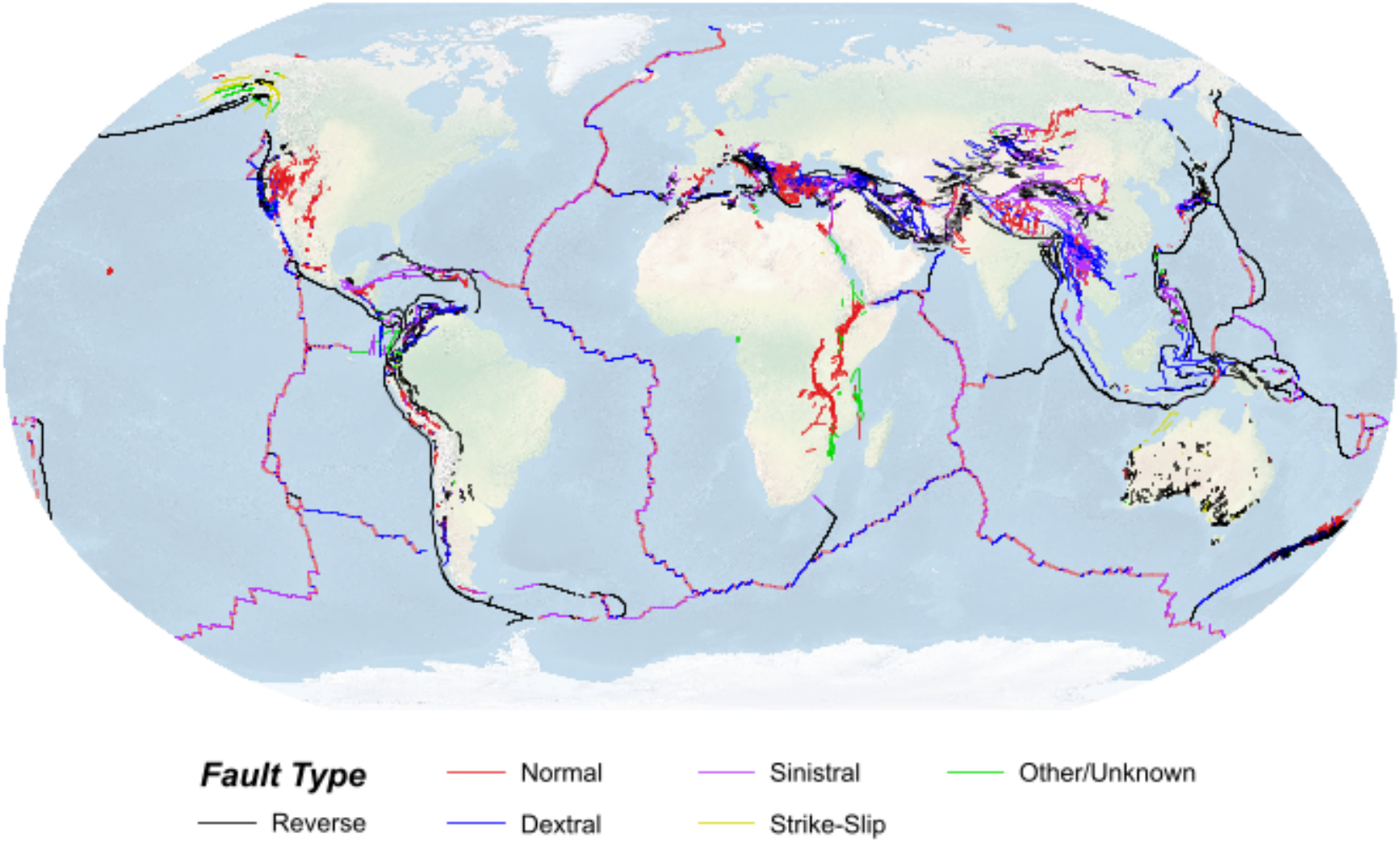
GEM Global Seismic Hazard Map



https://www.globalquakemodel.org/gem

Pagani et al., in revision, Earthquake Spectra

GEM GAF-DB



https://github.com/GEMScienceTools/gem-global-active-faults

GEM Global Active Fault Database (GAF-DB)

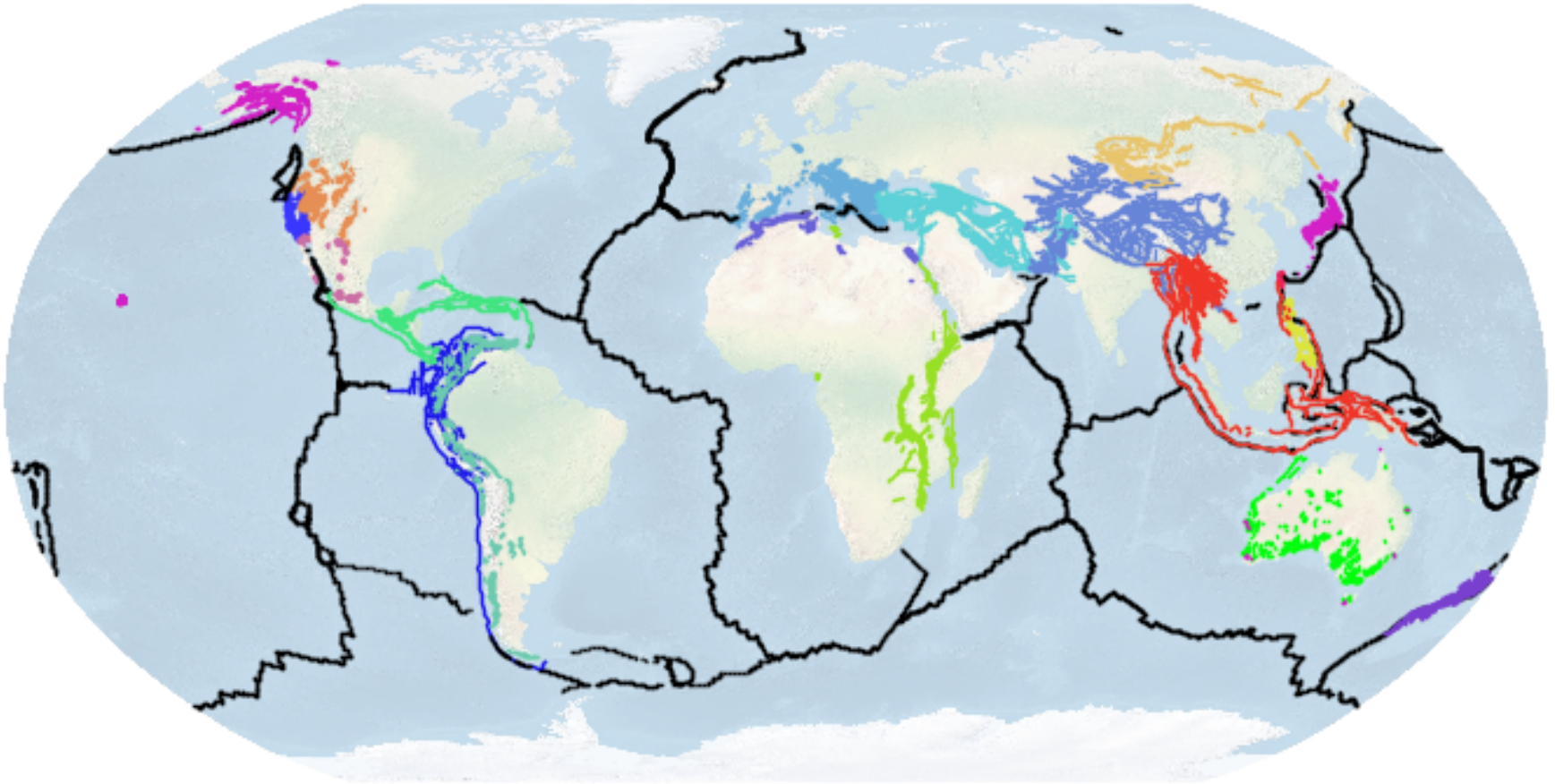
- First active fault database with ~global coverage

  ~13,500 faults

  ~10,500 slip rates (~77%)
- Compilation of 19 regional or thematic datasets
- Evolving, dynamic, built programmatically
- Map style and attributes/metadata geared toward hazard assessment

https://github.com/GEMScienceTools/gem-global-active-faults

GEM GAF-DB Sources



GEM GAF-DB Fault Sources

- Active Tectonics of the Andes
- Bird Plate Boundaries
- EMME
- EOS SE Asia
- GEM Faulted Earth
- GEM Carib Central Am
- GEM N. Africa
- GEM N.E. Asia
- HimaTibetMap
- Litchfield NZ 2013
- Macgregor AfricaFaults
- PHIVOLCS
- SARA
- SHARE
- Shyu Taiwan
- USGS Hazfaults 2014
- Villegas Mexico
- AUS_FSD
- UCERF3

GEM

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Fault Attributes

GEM

Attribute	Data Type	Description	Example
dip	tuple	Dip	(40,30,50)
dip_dir	string	Dip direction	W
downthrown_side_id	string	direction of downthrown side	NE
average_rake	tuple	Slip rake of fault	(45,25,55)
slip_type	string	Kinematic type	Sinistral
strike_slip_rate	tuple	Strike slip rate on fault	(1.5,0.5,2.5)
vert_sep_rate	tuple	Vertical slip rate	(1.5,0.5,2.5)
shortening_rate	tuple	Horizontal shortening rate	(1.5,0.5,2.5)
upper_seis_depth	tuple	Upper limit of seismicity	(0.,,)
lower_seis_depth	tuple	Lower limit of seismicity	(15.,10.,25.)
accuracy	integer	Denominator of map scale	40000
activity_confidence	integer	Certainty of neotectonic activity	1
exposure_quality	integer	How well exposed (visible) fault is	2
epistemic_quality	integer	Certainty that fault exists here	1
last_movement	string	Date of last significant earthquake	1865
name	string	Name of fault or segment	Polochic
fs_name	string	Name of fault system	Motagua-Polochic
reference	string	Paper used	Rogers and Mann, 2007
notes	string	Any relevant info	May be creeping
ogc_fid	integer	ID used by GIS	8
catalog_id	string	Global ID	CCARA_8

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geometry

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kinematics

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slip rates

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GEM

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(mle, min, max)

uncertainty

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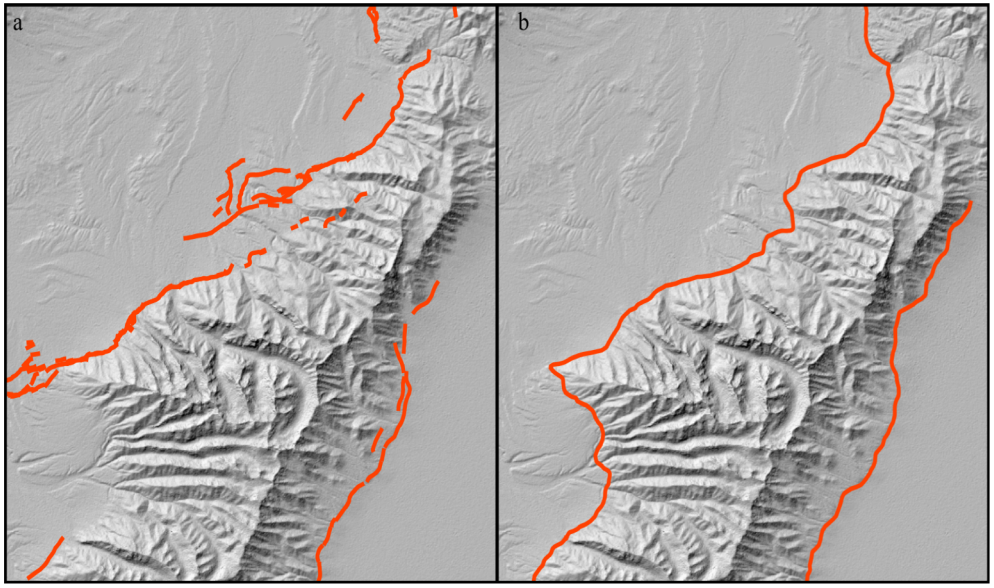
other info

Map style



Where possible,

- Each fault trace is an independent seismic source
- Traces should represent full-fault, Mmax rupture*
- Different than USGS Qfaults mapping style

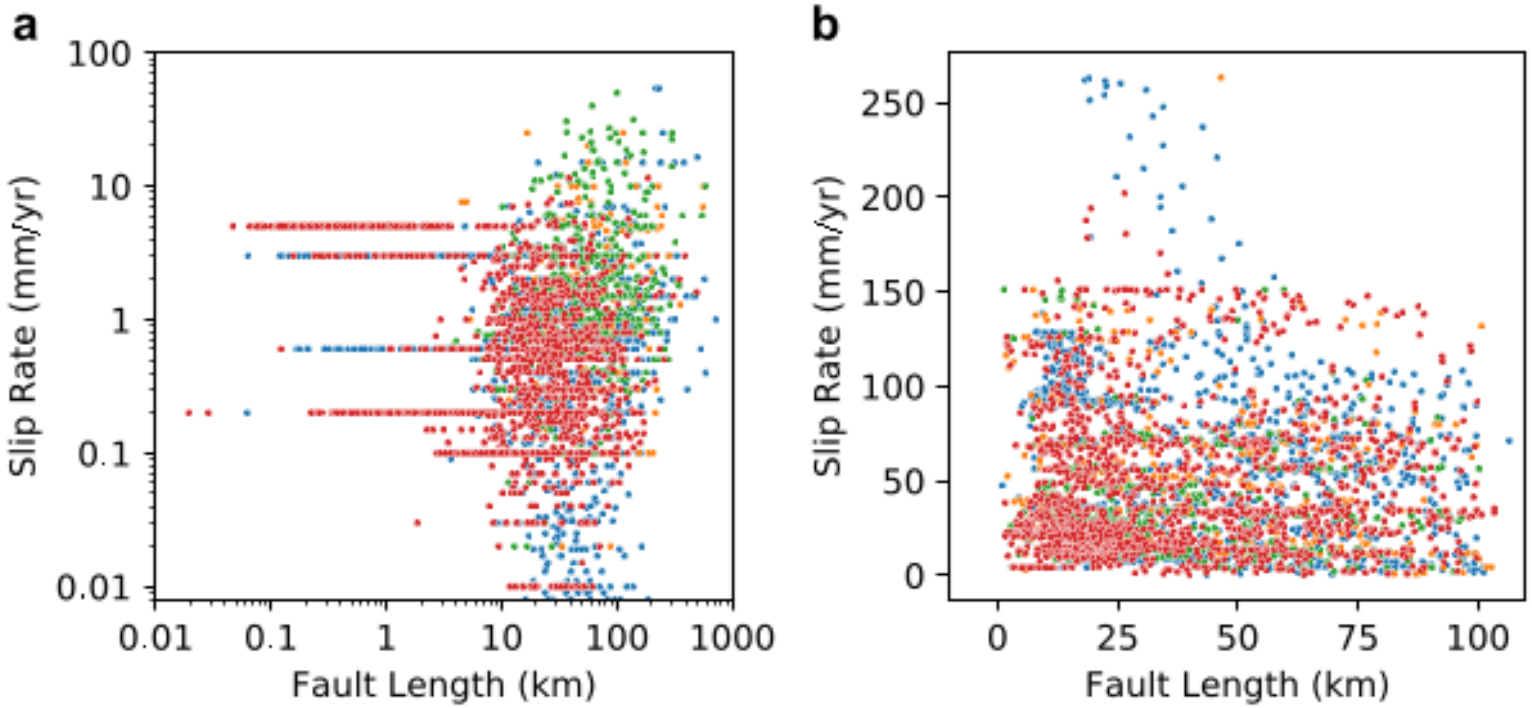
*yeah yeah Kaikoura I know

Slip rates and fault lengths

GEM

Continental

Oceanic



Normal reverse dextral sinistral

Styron and Pagani, revisions submitted, Earthquake Spectra

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Slip rates and fault lengths

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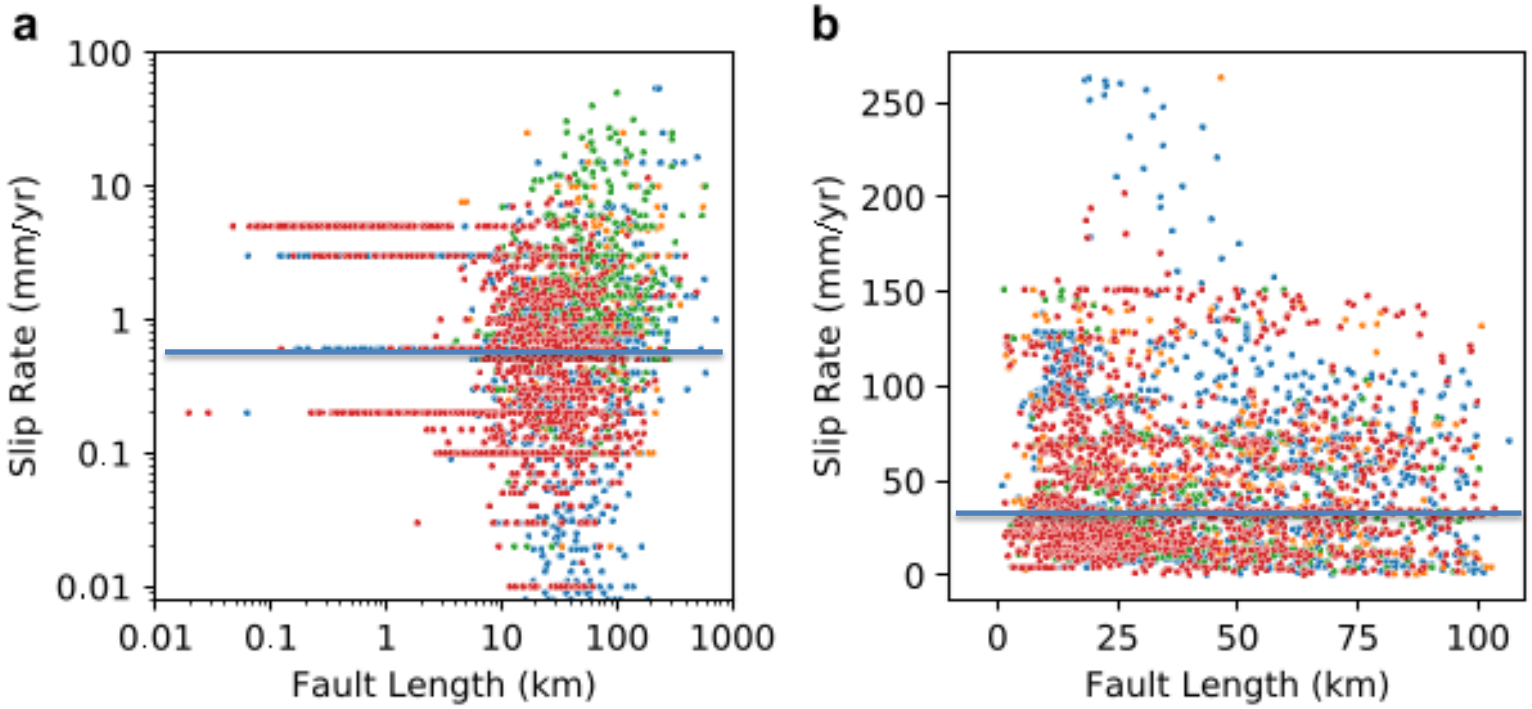

Normal reverse dextral sinistral

Median: 0.6 mm/yr

Median: 30 mm/yr

Styron and Pagani, revisions submitted, Earthquake Spectra

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Assembly

- GAF-DB assembled programmatically from constituent datasets
  - Each dataset is loaded, and attributes (columns) are selected and parsed/translated to GAF-DB format with custom Python functions for that dataset
  - Final GAF-DB catalog is assembled and then subject to some data QA checks
- Assembly takes ~1 minute
- Assembly performed each time constituent datasets are updated, or new databases are added, or GAF-DB schema changes
- Transparent, repeatable

Harmonization

- GAF-DB contains overlaps between different catalogs
- 'Harmonization' process removes faults from one catalog in case of overlaps
  - One catalog takes priority (faults retained)
  - In some cases, only intersecting (crossing) faults are considered
  - In others, all faults removed from lower-priority catalog if they intersect convex hull around higher-priority catalog
- Repeatable, automated, no modifications to data or catalogs

Data Formats

GEM

- The GAF-DB is a vector GIS database
  - Fault traces are polylines
    - One feature (row) per fault
    - No multi-line types
  - Metadata for each fault are GIS attributes

- GeoJSON format is ‘version of record’, for editing, storing, VCS
  - Plain-text vector GIS format
    - Primary webmap format, used by QGIS, Python, etc.
  - Conversions to GeoPackage (SQLite), ShapeFile, GMT, etc. done after assembly and harmonization

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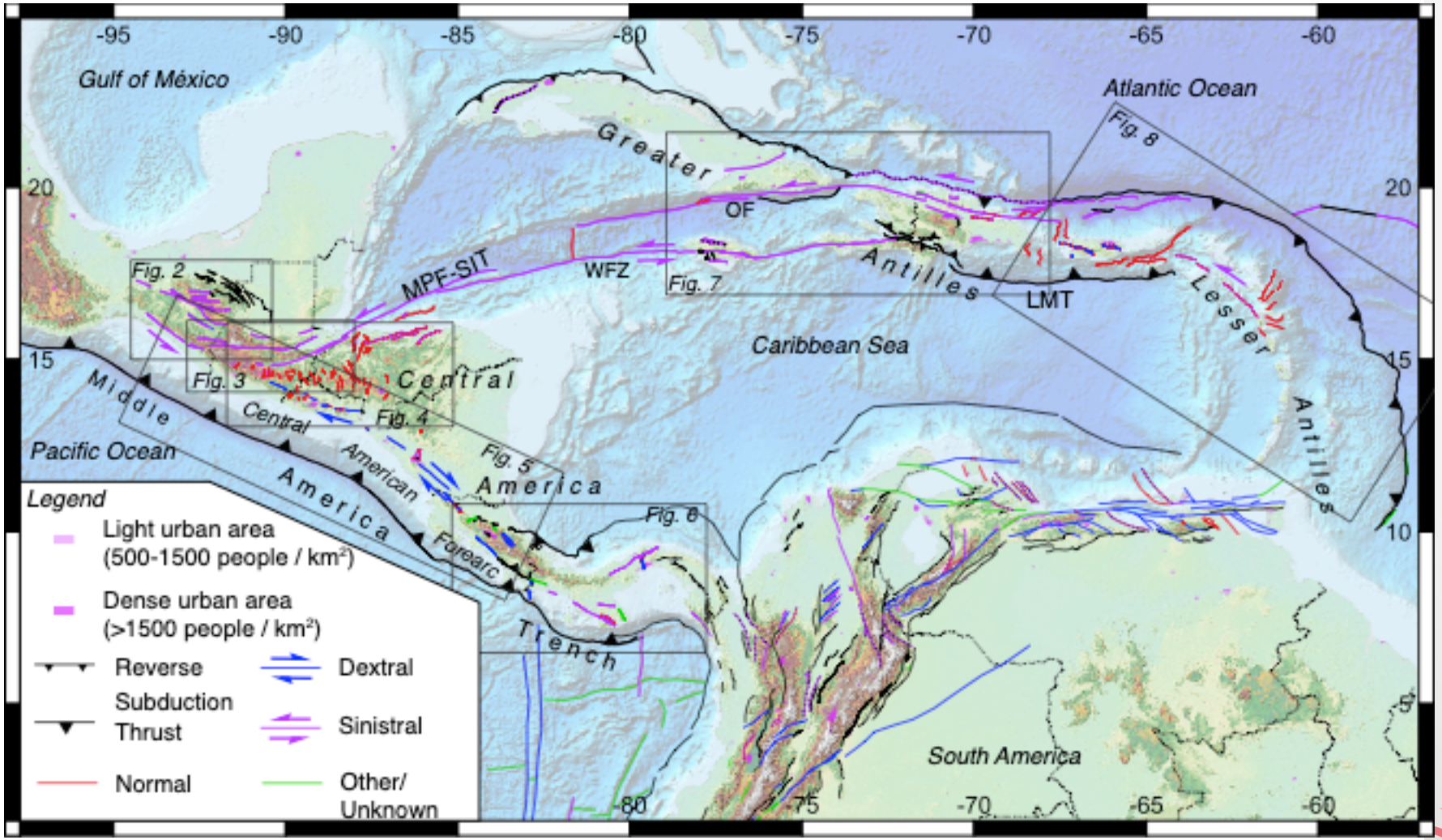
Updates and Version Control

- GAF-DB .geojson tracked with git version control software
  - 1 line in file per fault: easy per-fault change tracking
  - Updates, contributions, schema changes all recorded, undo-able
  - Software development best practices (merging, forking, pull requests and change reviews, etc.) work well

- Dissemination through GitHub
  - Extremely easy to publish changes
  - Users always have access to latest version + all previous versions

GEM Regional DBs: Central Am. Carib.



Styron et al, revisions submitted, NHESS

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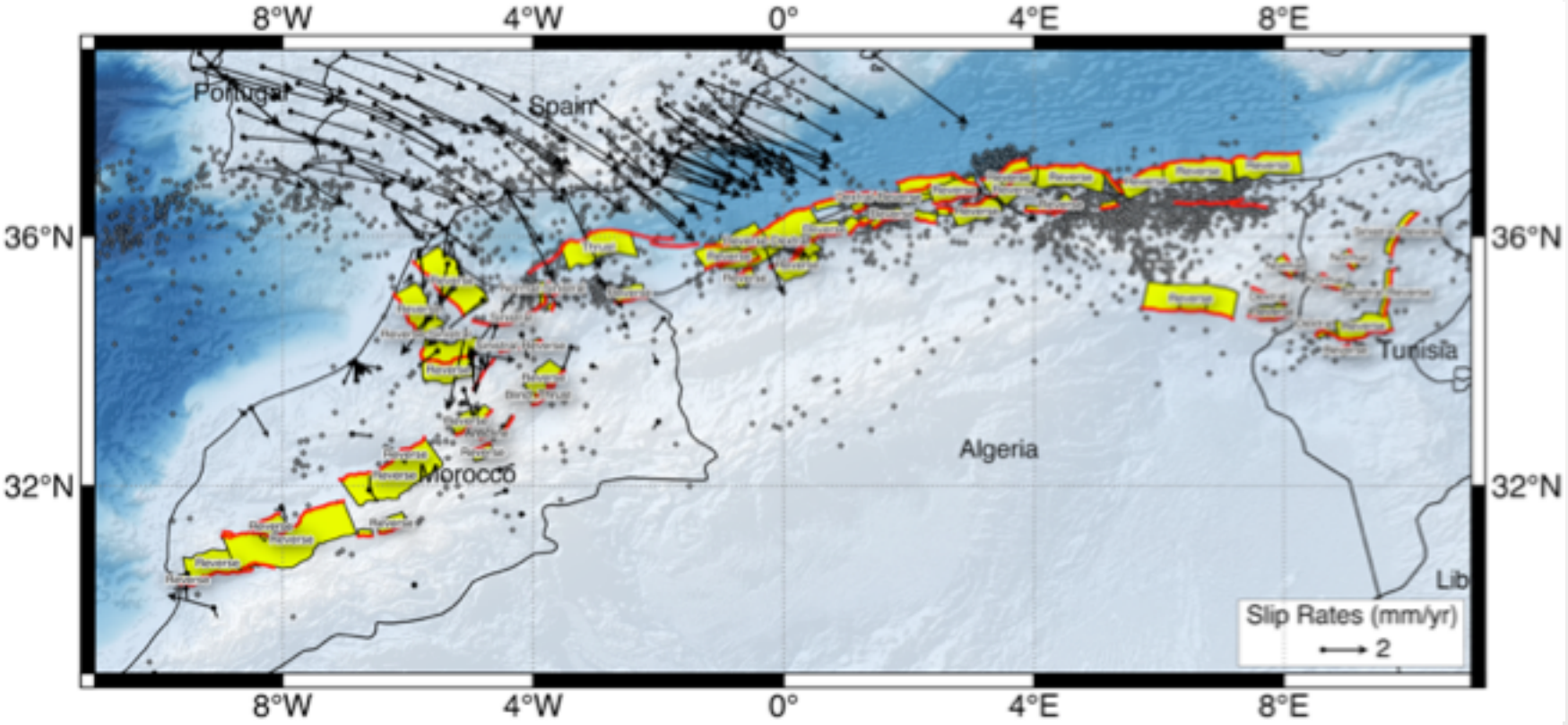
GEM Regional DBs: N. Africa



Poggi et al., in review, Bull. Earthquake Eng.

GEM Regional DBs: NE Asia

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Topics of Hazard + Geophysics interest

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- All of the following topics are areas of scientific debate with hazard implications

- If you're interested in working on them with hazard modelers, please email me:
- richard.styron@globalquakemodel.org

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GEM + Geodynamics: What can you do for GEM?

GEM

- PSHA based on many scientific components
  - Framework is reasonable
  - Most components could use refinement

- All aspects of earthquake processes have hazard and risk implications
  - With PSHRA implementation, can quantify human impacts
  - Collaboration can focus earthquake research, increase accuracy of hazard and risk models

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GEM + Geodynamics: What can GEM do for you?

GEM

- Areas for PSHA improvement are generally scientifically uncertain
- Different Earth behaviors imply different physics or geology
- Linkage of statistical models or simulations with physics allows for better testing of geophysical or geological hypotheses
  - Generate stochastic earthquake catalogs, ground motions
  - Test against observations

- BROADER IMPACTS

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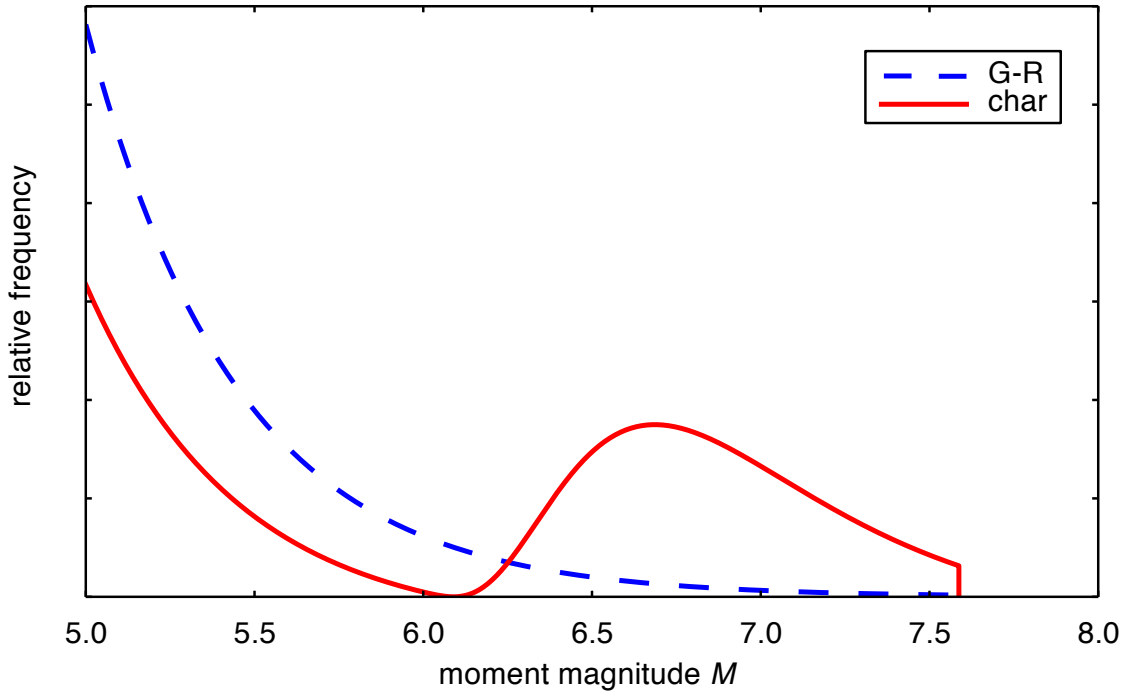
Fault magnitude-frequency distributions

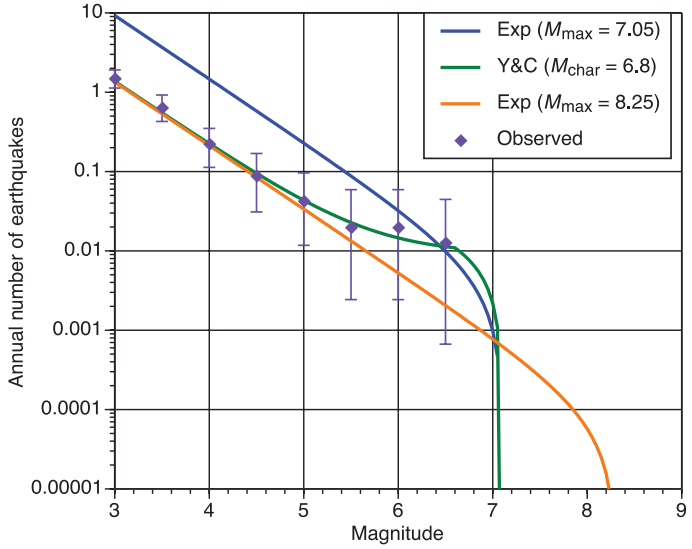
- The frequency / probability of earthquakes of different magnitudes on a fault is debated, very important for PSHA
  - Primary candidates: Gutenberg-Richter, Characteristic
- Fault MFDs + background MFD = regional GR MFD

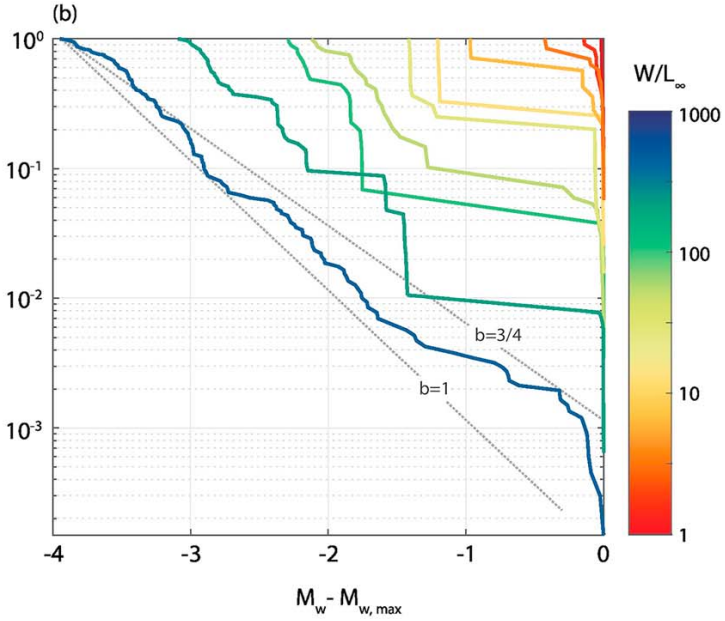


Styron and Hetland, 2014, GRL

Fault magnitude-frequency distributions

- Statistical analysis of paleoseismic datasets (weakly) supports characteristic-type MFDs
- Statistical and observational seismology favors Gutenberg-Richter
- Modeling studies generally produce characteristic-type MFDs (given most setups)
  - Controlling parameters?

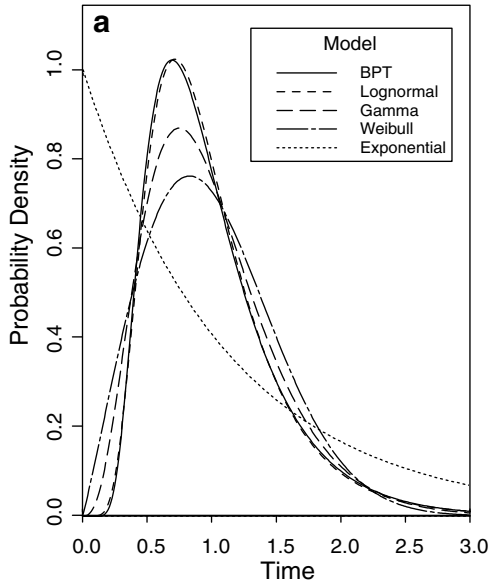


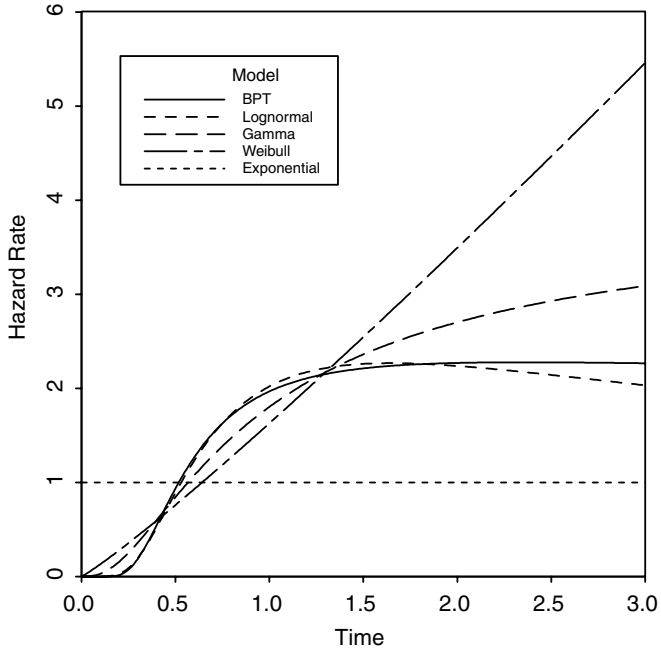


Hecker et al., 2013, BSSA; Cattania, 2019, GRL

Earthquake recurrence/ time dependence

- PSHA models are typically time-independent (Poisson)
  - Hazard doesn't depend on time since last event
- Quasi-periodic earthquakes on large faults are thoroughly embedded in earth science mindset
- Statistical seismologists often favor Poisson/time-independent recurrence

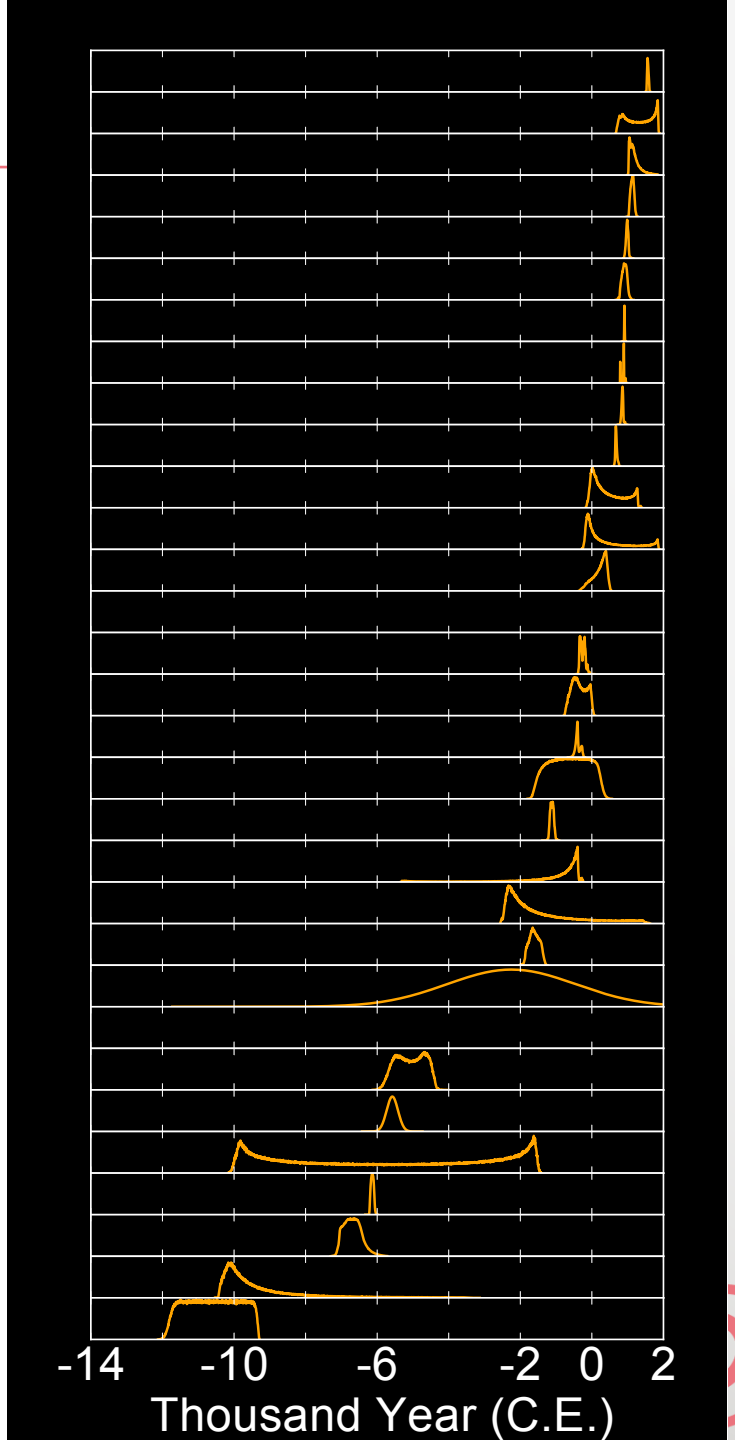




Matthews et al., 2002, BSSA

Earthquake clustering

- Abundant observational evidence for earthquake clustering within fault network (and maybe across the globe)
- Generally assumed to be from fault interaction (stress/strain triggering)
- Changing boundary/loading conditions could also be responsible



Styron and Sherrod, 2016, AGU fall meeting

Fault interaction

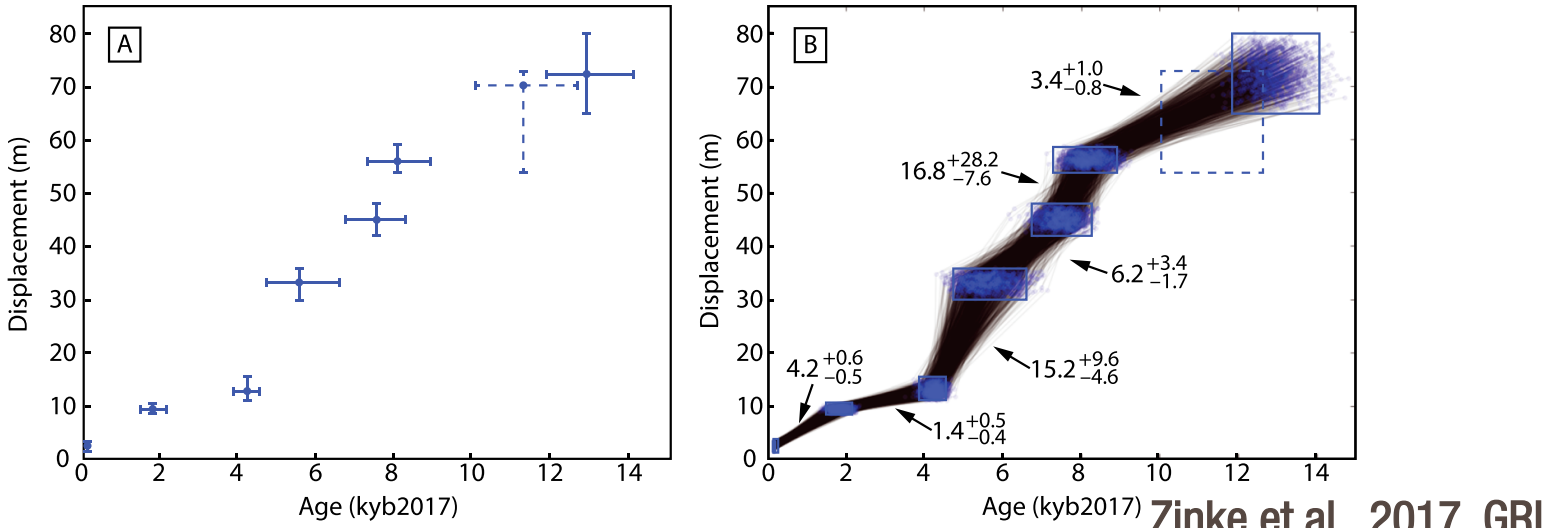
- If faults interact, modeling is more complicated
  - Independent probabilities of rupture calculated independently
  - Many interacting faults mean massively dependent probabilities, lots of state
  - Markov or probabilistic graphical model techniques?

- What are the different modes of fault interaction?
- What are the resulting patterns of seismicity?
- What do they imply about lithospheric properties or behavior?

Slip rates

- How much do slip rates change with time, and why?

- Do geodetic, paleoseismological, neotectonics and various bedrock geologic techniques measure the same processes?
  - No. But does how much it matter?
  - What best predicts near-future earthquake occurrence?



Zinke et al., 2017, GRL

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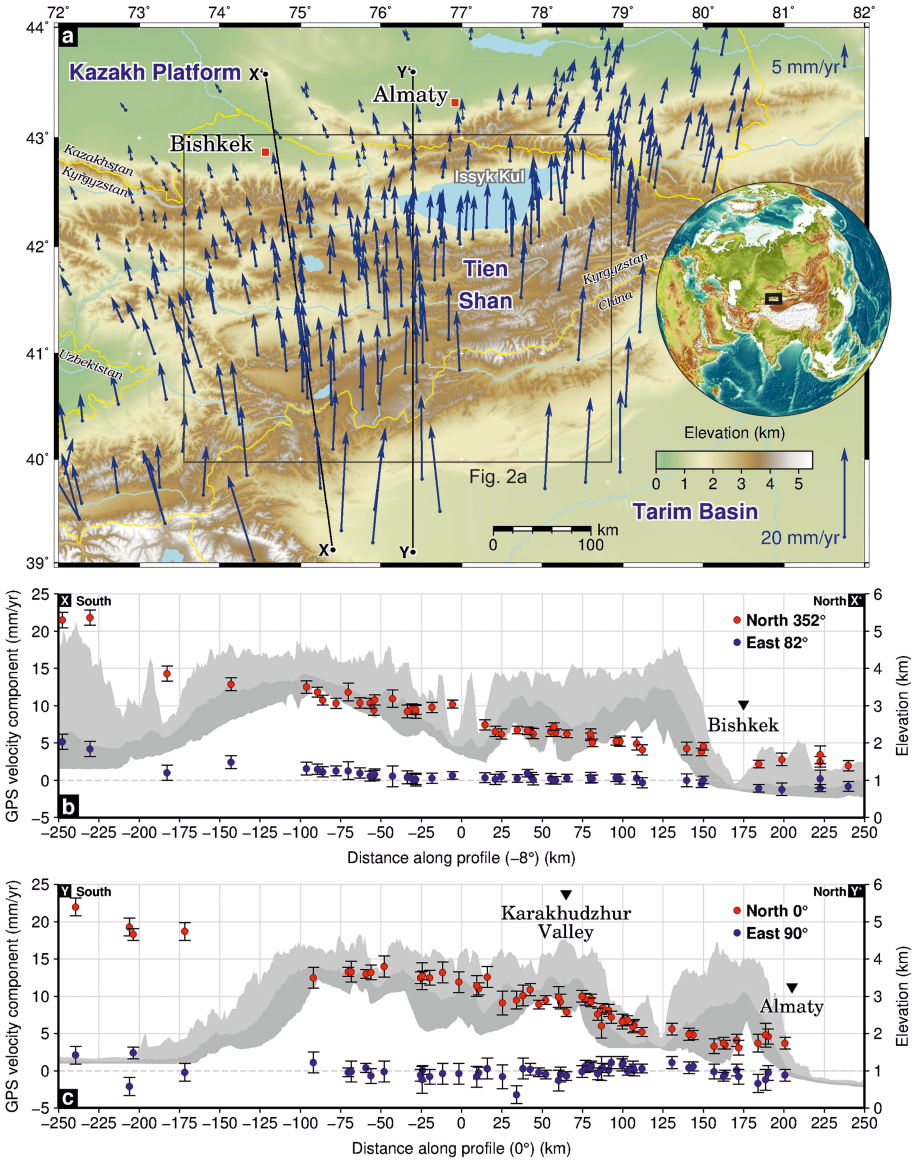
Slip rates

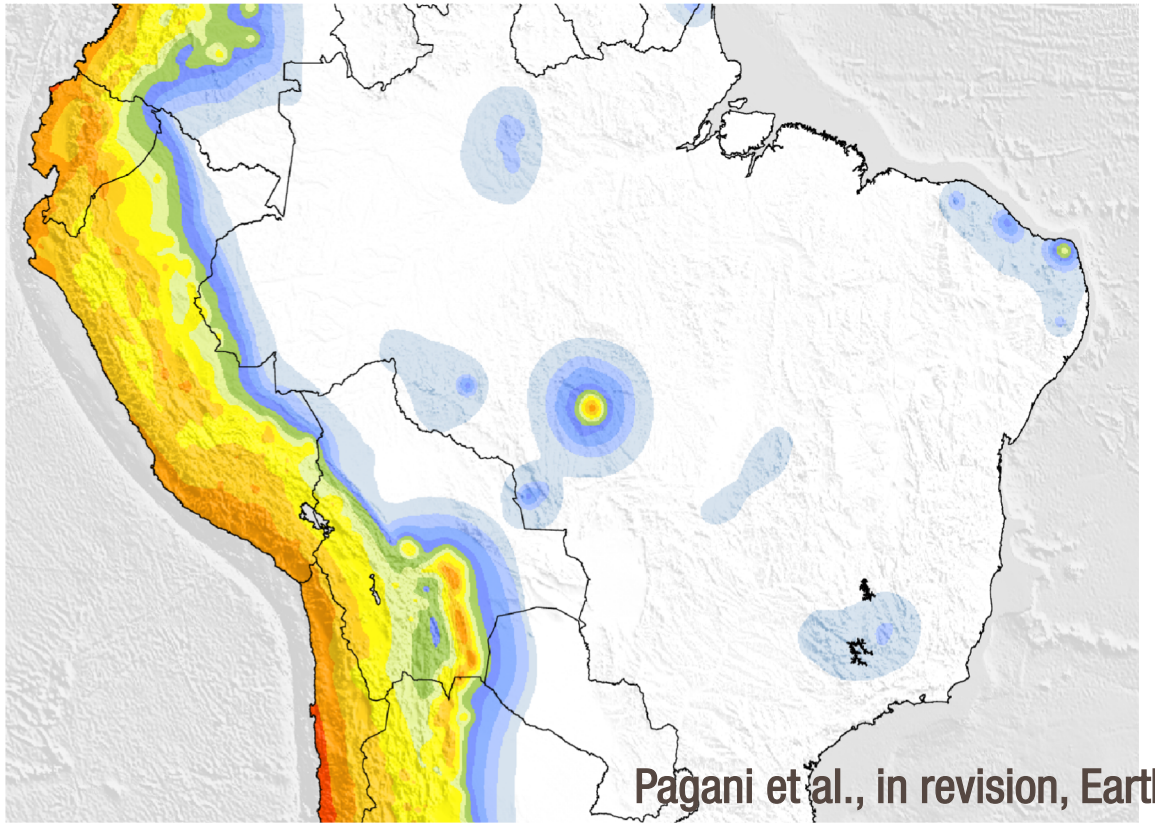
- How are regional deformation budgets distributed among faults?
- Can slip rates ‘trade off’ on faults in a network?
- Do areas of significant aseismic strain rate exist?



Campbell et al., 2019, Tectonics

Seismicity in slow-strain rate regions

- Very hard to estimate locations and rates of earthquakes in low-strain rate regions
- Cold crust -> high ground shaking -> PSHA bullseyes around past events



Pagani et al., in revision, Earthquake Spectra

Seismicity in slow-strain rate regions

GEM

- How different will patterns of seismicity be over the next 100 years compared to the past 100 years?

- Is seismicity caused by tectonic stress/strain or by other processes (post-glacial rebound, thermal stresses…)?

- Limited to pre-existing fault zones?

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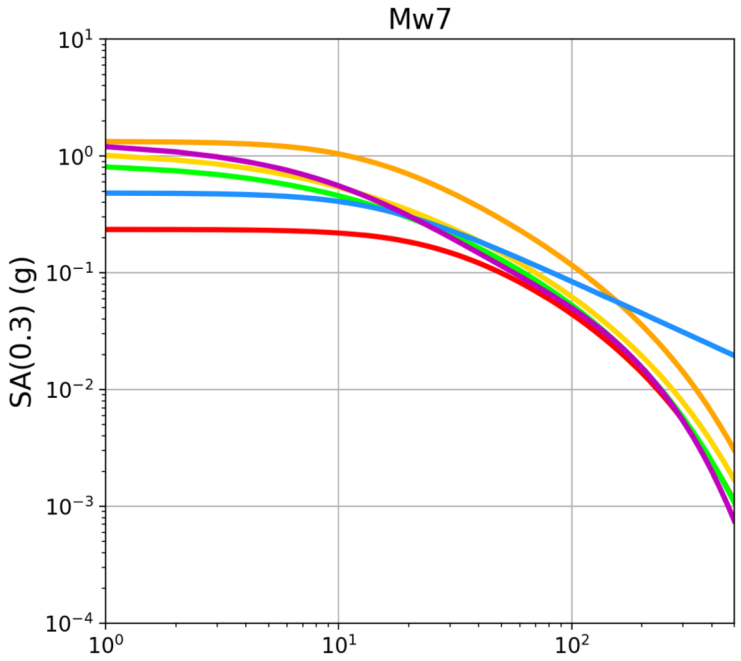
Ground motions

- Ground motion prediction equations have huge uncertainties, variability
- How to model seismic attenuation across tectonic boundaries?
- How to deal with variable site conditions within a model?
- Machine learning models?



Robin Gee, personal communication

GEM

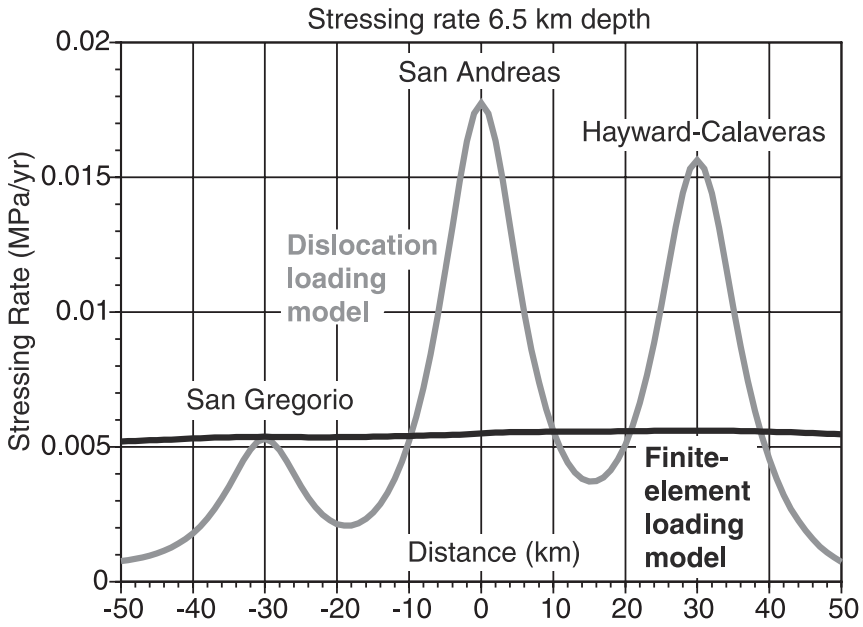
GLOBAL QUAKE MODEL .ORG

How are faults loaded?

- Fault loading through creep at depth means earthquakes are consequence of fault slip at depth

- Fault loading by elastic crustal stresses means earthquakes and fault slip are consequences of farther-field stress

- **Different loading models predict different modes of fault interaction and likelihood of off-fault seismicity**



Parsons, 2002, JGR

Questions? Comments?

- Thanks for watching/reading!

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